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**TURNING NUMBERS INTO KNOWLEDGE:  
MASTERING THE ART OF PROBLEM  
SOLVING**

Jonathan G. Koomey, Ph.D.

<http://www.numbersintoknowledge.com>

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### **Advance praise for *Turning Numbers into Knowledge*<sup>1</sup>**

This splendidly clear and concise introduction to the craft should be a foundation of every student's apprenticeship—and for those who missed it, a toolkit for a salutary retrofit later. How much more quickly and pleasantly we would discover truth if everyone followed these simple precepts!

**Amory B. Lovins**  
**Co-CEO (Research)**  
**Rocky Mountain Institute**

As information becomes ever cheaper, Dr. Koomey's book becomes ever more valuable. Masterful!

**Professor Erik Brynjolfsson**  
**Sloan School of Business, Massachusetts Institute of Technology**  
**Co-director, Center for E-Business @ MIT**  
**Co-editor, *Understanding the Digital Economy***

Dr. Koomey has produced an absolute home run! A witty, incisive primer on critical analytical thinking. Required reading for business analysts, planners, and strategists - critical insight for players in the Internet economy.

**Tod Loofbourrow**  
**President and CEO**  
**Authoria, Inc.**

Here at last is the definitive guide for beating information overload and responding to the current anti-science, anti-environment backlash. This remarkable book will empower both professionals and neophytes.

**Professor John Harte**  
**Energy and Resources Group, University of California, Berkeley**  
**Author of *Consider a Spherical Cow: A Course in Environmental Problem Solving***

The greatest challenge facing educators, institutions, and businesses is the inculcation of rigor and fact-based analysis into the psyches of future leaders. *Turning Numbers Into Knowledge* is the tool for organizations to accomplish this essential task.

**Ephraim Heller**  
**Founder, Therasense, Inc.**

Through its excellent theoretical and practical insights, this book shows how to become a superb analyst. Read it!

**Professor Lene Sørensen**  
**Center for Tele-Information, Technical University of Denmark**

I thought I was good at crunching numbers until I read *Turning Numbers Into Knowledge*. It's a great tool for improving your own use of numbers AND for seeing through the smoke screens of others

**Lee Schipper, Ph.D.**  
**Senior Scientist**  
**International Energy Agency**

This gem of a book should be required reading for anyone who analyzes information--and that means everyone! *Turning Numbers into Knowledge* teaches readers to be critical of

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everything they hear, see, and read, thus making them more effective scientists, social scientists, and citizens.

**Professor Richard F. Hirsh**

**Department of History and Science & Technology Studies, Virginia Tech**

**Author of *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System***

All decision-makers need to read this book. It explains, in clear and useful terms, how to use the ever-growing flow of data in our society. But that's only the start. *Turning Numbers into Knowledge* will help the reader become a better thinker, and it is a rare book that can make that claim.

**Hal Harvey**

**President**

**Energy Foundation**

*Turning Numbers into Knowledge* is a terrific resource for students, and an essential aid for researchers, from undergraduates on up. Dr. Koomey's book will be required reading for my next research seminar.

**Professor Eban Goodstein**

**Department of Economics, Lewis and Clark College**

**Author of *What Tradeoff? Fictions and Facts About Jobs and the Environment***

I like this book! Both practical and philosophical, Koomey's work gives readers the skills to extract, communicate, and most importantly to understand knowledge embodied in numbers.

**Eric Bergman, Ph.D.**

**Sun Microsystems**

**Author of *Information Appliances and Beyond***

*Turning Numbers Into Knowledge* is an insightful, entertaining, and practical guide to critical thinking in the Information Age.

**Professor Stephen J. DeCanio**

**Department of Economics, University of California, Santa Barbara**

Knowing what numbers really have to say in today's data-intensive world is knowing the difference between fact, fiction, and the yet unknown—and key for personal and professional success. *Turning Numbers into Knowledge* is a must read!

**Kathleen Hogan, Ph.D.**

**Director, Climate Protection Division**

**US Environmental Protection Agency**

*Turning Numbers into Knowledge* is the long-awaited Rosetta stone between two worlds: that of the undergraduate student aspiring to make a difference in the world, and that of the professional policy analyst working to make sense of it. It will enlighten and empower a whole generation of students who want to change policy and need to know how.

**Professor Michael Maniates**

**Departments of Political Science and Environmental Science, Allegheny College**

Using numbers to describe the world is an art that takes understanding, skill, and courage. This book supplies the artist with perspective and the practitioner with reliable equipment

**Kim Taylor, Ph.D.**

**Research Program Manager**

**US Geological Service**

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This book contributes to the advancement of technical communication, without which knowledge is useless. It provides insight into breakdowns in both expression and interpretation, and offers tangible tools and techniques for identifying, correcting, and avoiding such breakdowns.

**Dianne Hawk, Ph.D.**

**Senior Consultant**

**Barkovich and Yap, Inc., Consultants**

Dr. Koomey's book is a practical and powerful tool that addresses a critically important topic. It is exemplary for its clarity and accessibility.

**Mark Morland**

**History and Economics Instructor**

**The Colorado Springs School**

*Turning Numbers Into Knowledge* is the best guide to practical problem solving that I have ever read.

**Laura M. Newcomer, Ph.D.**

**University of Washington, Seattle**

*Turning Numbers Into Knowledge* is a godsend to analysts everywhere. It is the single best resource I have encountered on the practice of data analysis in the real world.

**Cooper Richey**

**Enron Corporation**

*Turning Numbers into Knowledge* teaches tricks that most problem solvers only learn after years on the job. Give yourself an edge: Read this book!

**Barbara Barkovich**

**Principal**

**Barkovich and Yap, Inc., Consultants**

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I'd always believed that a life of quality, enjoyment, and wisdom were my human birthright and would be automatically bestowed upon me as time passed. I never suspected that I would have to learn how to live—that there were specific disciplines and ways of seeing the world I had to master before I could awaken to a simple, happy, uncomplicated life.

--Dan Millman--

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### ***AUTHOR'S BIOGRAPHY***

Jonathan G. Koomey is currently a staff scientist at Lawrence Berkeley National Laboratory, one of the nation's foremost research laboratories. He holds M.S. and Ph.D. degrees from the Energy and Resources Group at the University of California at Berkeley, and an A.B. (Cum Laude) in History of Science from Harvard University. He is the author or co-author of seven books and more than one hundred articles and reports on energy efficiency, climate change, and environmental policy. He serves on the Editorial Board of the journal *Contemporary Economic Policy*, and has appeared on Nova/Frontline, CNBC, and KQED radio. In 1993, his report *Cost-Effectiveness of Fuel Economy Improvements in 1992 Honda Civic Hatchbacks* won the Fred Burgraff Award for Excellence in Transportation Research from the National Research Council's Transportation Research Board.

Dr. Koomey has been fascinated by numbers since he was a young boy. In graduate school, he amazed and annoyed his friends with his love of back-of-the-envelope calculations. Outside of work he enjoys practicing Aikido, hiking, cycling, running, and playing classical contrabass.

### ***FOREWORD***

Jon Koomey writes books the old fashioned way: by accumulating experiences, anecdotes and examples over a lifetime of hard work, and refining them into a compact ingot of pure gold. The reader is offered a rare gift indeed—the essential elements of dozens of fine books, the collective wisdom of countless scientists and commentators, and a handful of the most inspired comic strips ever to grace the daily newspaper. In an era where so many books, once read, become disposable, Dr. Koomey has created an enduring reference. His focus on the Internet and his commitment to keeping its content fresh through an ongoing electronic dialogue with readers are laudable indeed. Read this book and apply its many lessons not just to school or work, but to *life*!

Chris Calwell  
Founder, ECOS Consulting, Inc.

### ***BLURB FOR COVER***

This is a book about numbers, but not about math. An award-winning young scientist teaches you the art of analysis, revealing tools, tricks, and heretofore unwritten rules that the best real-world problem solvers know by heart.

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**“Mr. Casals, you are 95 and the greatest cellist that ever lived,” a young reporter commented. “Why do you still practice six hours a day?” Casals replied, “Because I think I’m making progress.”**

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### *PREFACE*

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**Whatever failures I have known, whatever errors I have committed, whatever follies I have witnessed in private and public life have been the consequence of action without thought.**

**--Bernard Baruch--**

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Quantitative problem solving is the process by which we take *numbers* and transform them into *knowledge*, using our instincts and experience to fill in when we don't have all the answers. While the technical aspects of this process are taught at many universities, the *art* of problem solving is rarely discussed and even more rarely written down. This book teaches the intricacies of that art, and will help you become a first-rate analyst in your chosen field.

After reading this book, you will be far better equipped to make independent judgments about analysis used by others. You will know which key questions to ask, so you need never again be at the mercy of those who traffic in “proof by vigorous assertion.”<sup>2</sup> You will also be more effective at conducting and presenting your own analyses, no matter what the topic.

Mastering the art of problem solving takes more than proficiency with basic calculations: it requires familiarity with how people use information, and requires learning about things as diverse as ideology, telling good stories, and distinguishing facts from values. To give you a feeling for what to expect, I present an annotated chapter list below.

#### **ANNOTATED CHAPTER LIST**

This book contains seven major sections, separated into thirty-eight short chapters. Each chapter is compact and self-contained, and each summarizes key lessons I've learned over the years.

*I. The information explosion:* This section briefly describes how analysis can help reduce the information overload that affects us all.

*II. Things to know:* These chapters summarize ideas to keep in mind as you read the rest of the book. More experienced analysts should delve into the ones they find most intriguing, and skim the rest.

*1. Beginner's mind:* Start fresh and approach any problem like a beginner would, and you'll surely see things that others will miss.

*2. Don't be intimidated:* The difference between success and failure often depends on whether you are intimidated. By consciously refusing to be cowed, you can stack the odds in your favor.

*3. Information, intention, and action:* This chapter describes how humans respond to events, exploring the connections between what we measure, what we assume, and what we choose to do.

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4. *Peer review and scientific discovery:* Progress in science can be subject to human frailty, just like any other human endeavor. The end result, however, is something you can count on, in large part because of the peer review process.

III. *Be prepared:* A key determinant of your effectiveness is the quality of your preparation. Whether you're building a house or chairing a meeting, preparation for the analysis tasks at hand can turn a potential disaster into a triumph.

5. *Explore your ideology:* Ideology provides a simplified model of the world that reflects our values and experiences, and prevents paralysis in the face of the many choices we make every day. Make sure you know your own belief system and that of others.

6. *Get organized:* Working and living in chaos is like running a marathon with your feet tied together. Get your life in shape and keep it that way.

7. *Establish a filing system:* Few mistakes are more maddening than knowing you have seen a relevant article and not being able to find it. By creating a good filing system, you can prevent this annoyance from ever happening again.

8. *Build a toolbox:* My analytical toolbox is the set of tricks and techniques that I can pull out to solve particular problems. This chapter describes some key tools to consider for your own.

9. *Put facts at your fingertips:* Every analysis requires data. Unless you've memorized the encyclopedia, you'll still want to keep some key reference sources within easy reach. This chapter describes the ones I find most useful.

10. *Value your time:* Remember that your time is your life, and that if someone is wasting your time, they are stealing your life. Identify your most productive times of day and protect yourself from interruptions during those periods. Unplug the phone. Go to the library. Take control of those times!

IV. *Assess their analysis:* When faced with the assertions of others, it's good to know the right questions to ask. These chapters summarize hard-won knowledge about deciphering other people's analyses.

11. *The power of critical thinking:* Careful critical thinking is at the root of all good analysis. When the steps described in this chapter become second nature, you will have mastered its essence.

12. *Numbers aren't everything:* Not everything that matters can be quantified, so make sure the unmeasurable doesn't fall through the cracks.

13. *All numbers are not created equal:* Numbers and calculations characterizing the physical world are almost always more certain than those describing human behavior. Many analysts wrongly imply that forecasts based on economic data are just as solid as science. They aren't, so be forewarned.

14. *Question authority:* This catch phrase of the 1960s is still applicable today. Authority figures can be wrong or biased, so investigate their assertions in the same way that you'd examine those of someone with whom you're not familiar.

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15. *How guesses become facts:* Always remember that “official” statistics are based on calculations that are often poorly documented, incorrectly cited, or otherwise hazardous to your intellectual health.

16. *Don't believe everything you read:* Maintain a healthy skepticism, even of well established sources. In this age of instant information transmittal, rumor and error seem to propagate even more quickly than truth.

17. *Go back to the questions:* Any time you rely on survey data to make an important decision, refer back to the actual questionnaire upon which the survey data are based or risk misinterpreting the data.

18. *Reading tables and graphs:* First check for internal consistency, then see if the results contradict other facts you know to be true. Search for cognitive dissonance; any discrepancy between the author's results and what you already know will help you investigate further.

19. *Distinguish facts from values:* Don't be fooled by technical people who portray their advice as totally rational, completely objective, and value-free. If they have made a choice, they have also made a value judgment.

20. *The uncertainty principle and the mass media:* Just as the observer of a subatomic particle can disturb that particle by the act of observation, the observer of an institution can disturb that institution by observing and reporting on it. Members of the media (and the analysts who inform them) should take responsibility for the power they wield.

V. *Create your analysis:* Everyone develops his/her own techniques for creating cogent analyses, and in this section I summarize those I've learned. The importance of organization, clear thinking, careful definitions, systematic exposition, scrupulous documentation, and consistent comparisons cannot be overestimated, and you'll learn about each of these here.

21. *Reflect:* Free yourself from interruptions and give yourself time to reflect. Without such time, you'll never achieve your full problem-solving potential.

22. *Getting unstuck:* Everyone gets stuck sometimes, but it need not hobble your efforts if you use the tricks in this chapter.

23. *Inquire:* When faced with a problem outside your expertise, don't surrender! It's an advantage to be unconstrained by the mental shackles most disciplines place on their practitioners. Some of the most important insights in modern thought come from people who could think “outside the box.”

24. *Be a detective:* Detectives are real-world practitioners of the scientific method. The time-honored techniques of these seasoned problem solvers can help you in your efforts.

25. *Create consistent comparisons:* People often relate best to anecdotes. A consistent comparison is a well chosen set of two anecdotes that illustrates your point in a compelling way. It is a powerful technique, and one well worth learning.

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26. *Tell a good story*: Scenario analysis is the art of structured storytelling, and it's an essential tool for any good analyst. Most people don't realize that this art is both highly developed and pertinent to many everyday situations.
27. *Dig into the numbers*: Don't be shy about delving into the actual numbers, even if you're a highly paid executive. You'll learn things you would never see if someone else crunches the numbers.
28. *Make a model*: Models are “laboratories for the imagination,” and this chapter explores the subtleties of using them to explain the world around you.
29. *Reuse old envelopes*: You can calculate almost anything using only common knowledge--you just need to learn how to put this knowledge to use, and this chapter (which focuses on back-of-the-envelope calculations) is just the thing to help you do it.
30. *Use forecasts with care*: The future is uncertain, but people keep trying to forecast it anyway. Numerous pitfalls await, and without a keen eye for the tricks of this trade, you'll be hard pressed to avoid them.
31. *Hear all sides*: In any intellectual dispute, it pays to hear two well-prepared debaters argue their points before drawing any conclusions. Always make such debates fodder for your deliberations and your decisions will benefit.
- VI. *Show your stuff*: Once you've done good work, you'll want to present it effectively to readers or listeners. The chapters in this section give insights into making your results “grab” your audience, designing good tables and figures, and using those tables and figures to convey your key points. The section concludes by exploring effective use of the Internet in publishing your analysis.
32. *Familiarity breeds interest*: The first rule of data presentation is to know your audience and present compelling information in a form it can easily grasp. Most analysts forget that other people don't care nearly as much about their results as they do.
33. *Document, document, document*: An astounding number of analysts routinely omit vital data and assumptions from their reports, but you should avoid this pernicious practice. The best analysts document *everything*, giving credit where credit is due, leaving a trail for them to remember, and creating a trail for others to follow. Documentation is also a key step in checking your work, because it forces you to think clearly about your analysis.
34. *Let the tables and graphs do the work*: When writing technical reports, create the analysis, tables, and graphs first, then write around them. If the analysis is well thought out, the tables and graphs well designed, and the audience clearly defined, the report should practically write itself.
35. *Create compelling graphs and figures*: Follow Edward Tufte's rules for graphical excellence and avoid the most common pitfalls in designing charts and graphs. Your goal should be to give to the reader “the greatest number of ideas in the shortest time with the least ink in the smallest space.”<sup>3</sup>

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36. *Create good tables:* A well-designed table is a work of art, while a sloppy one is worse than useless. Make your tables a resource that your readers keep as a reference for many years to come.

37. *Use numbers effectively in oral presentations:* Even veteran presenters show too many of the wrong numbers. Present only those numbers that support the story you are telling, and focus on that story, NOT the numbers themselves.

38. *Use the Internet:* The old ways of publishing are fast being supplanted by web-based approaches. Learn about these new tools and put them to work for you.

*VII. Some parting advice—Creating the future:* This chapter gives perspective on why we use analysis in the first place. Understanding the world is a prerequisite for making it better!

## WHO SHOULD READ THIS BOOK

This book grew out of my experience in training analysts I've hired in the past decade. It is written for beginning problem solvers in business, government, consulting, and research professions, and for students of business and public policy. It is also intended for supervisors of such analysts, as well as entrepreneurs (who may not consider themselves analysts, but who need to create analyses to justify their business plans to potential investors). Finally, it covers many topics that journalists who focus on scientific or business topics will find useful.

## HOW TO USE THIS BOOK

There is no need to read the chapters in order. Go straight to those that interest you most, but skim the chapters you skip. You just might see something useful there that you did not expect.

Most chapters have “links” to other chapters, with graphical signposts indicating which chapter or major section to investigate for each link (the relevant chapter number appears inside). These signposts look like the link to Chapter 14 that appears in the right margin opposite this line. In the electronic versions of this book these links are “live,” so that readers can jump to related sections with ease.

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All Uniform Resource Locators (URLs) discussed in the book are enclosed in triangular brackets, to set them off from the text. They appear as follows: <<http://www.lbl.gov>>. Of course, the brackets and any punctuation marks that precede or follow them are not part of the URL.

All URLs, as well as many key data files, are available in electronic form at <<http://www.numbersintoknowledge.com>>. If you have questions, comments, or suggestions, you can post them at this site. I'll evaluate them for inclusion in the next edition. I'm particularly interested in examples of large and public analytical blunders by people who should know better, examples of bad or good tables and graphs, and suggestions for how the book can be improved or expanded.

The endnotes contain references, attributions, and further information for the interested reader. The *Further Reading* at the end of the book does not attempt to be comprehensive. Rather, it contains selected sources for each chapter that I regard as most crucial for mastering the material. If I mention a book, I include it in the further reading section for the chapter in which I refer to it. At the beginning of the further reading section, I also include

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the “Top Ten” list of my very favorite sources on this topic, which (in my opinion) are the “must read” items that all serious analysts should have on their shelf.

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**Like all other arts, the science of deduction and analysis is one which can only be acquired by long and patient study.**

**--Sherlock Holmes--<sup>4</sup>**

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### Endnotes

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<sup>1</sup> Affiliations listed for informational purposes only. The opinions expressed do not necessarily represent those of the institutions listed.

<sup>2</sup> I am indebted to Amory Lovins for this phrase.

<sup>3</sup> Tufte, Edward R. 1995. *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press. Fourteenth printing. p. 51.

<sup>4</sup> From *A Study in Scarlet*. Contained in Baring-Gould, William S. ed. 1976. *The Annotated Sherlock Holmes*. Volume I. New York, NY: Clarkson N. Potter, Inc./Publisher. 15<sup>th</sup> printing. p. 159.